Trends in the Hadley cell over the last two decades

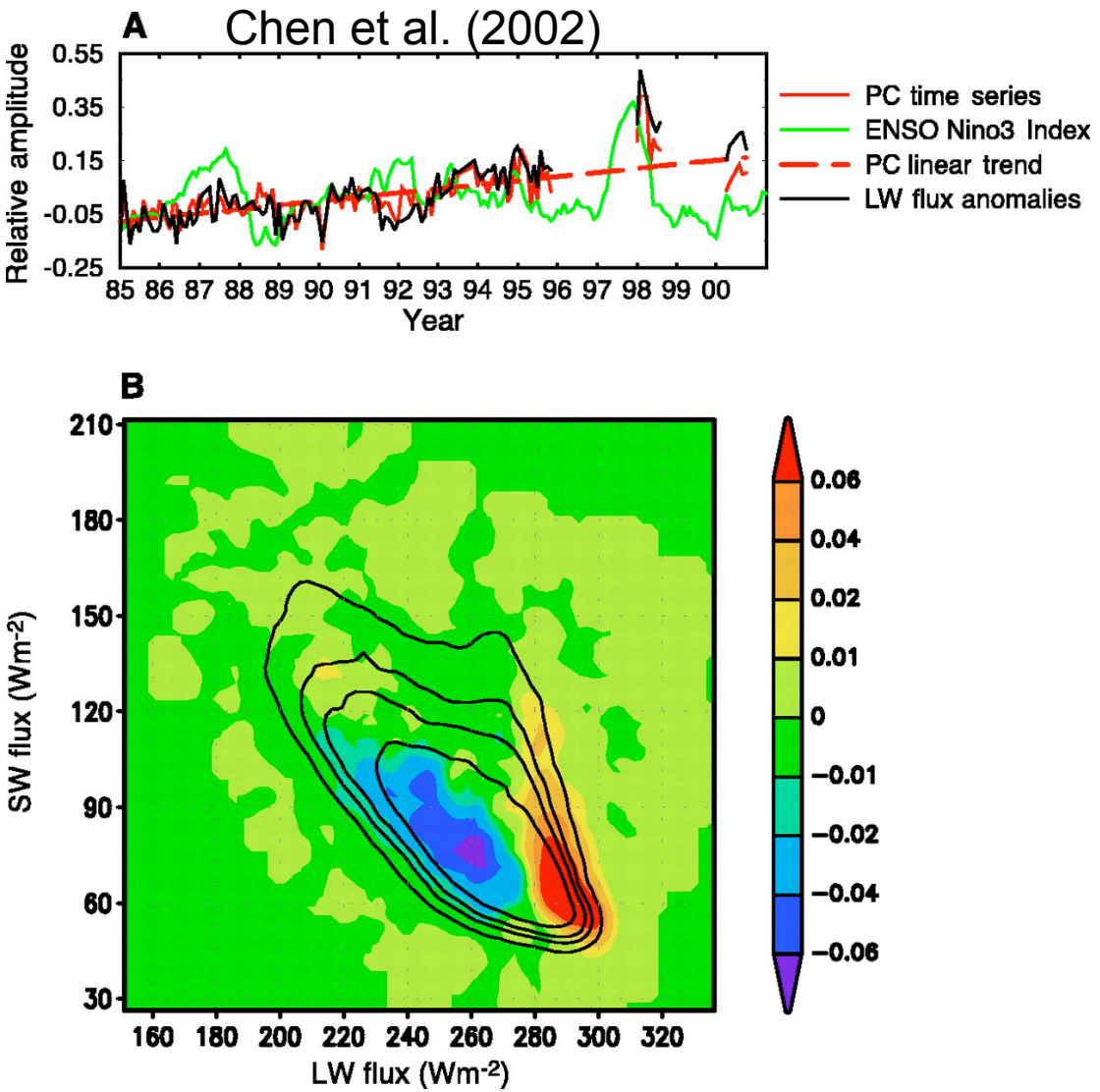
Amy Clement and Christos Mitas
Rosenstiel School of Marine and Atmopsheric Sciences

CERES Science Team meeting, GFDL, May 3-5, 2005

Tropical climate trends

Tropical mean radiative flux trends coincide with increased extremes of high OLR and low absorbed SW

Stronger tropical circulation??



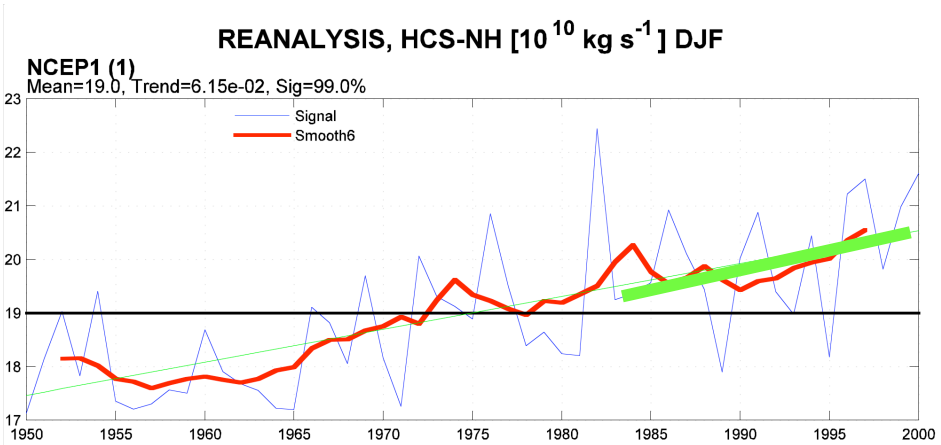
- Clement and Soden (2005) showed that
  - Stronger circulation is not related to tropical mean radiative fluxes in an obvious (or robust) way *(but there is a net decrease in absorbed SW with stronger circulation in AM2 due to increased low cloud cover)*
  - But a stronger circulation does impact the extremes (as in Chen et al. 2002)

- Has the circulation increased over the last two decades?
  - Reanalyses
  - IPCC 20th century simulations
  - AMIP runs

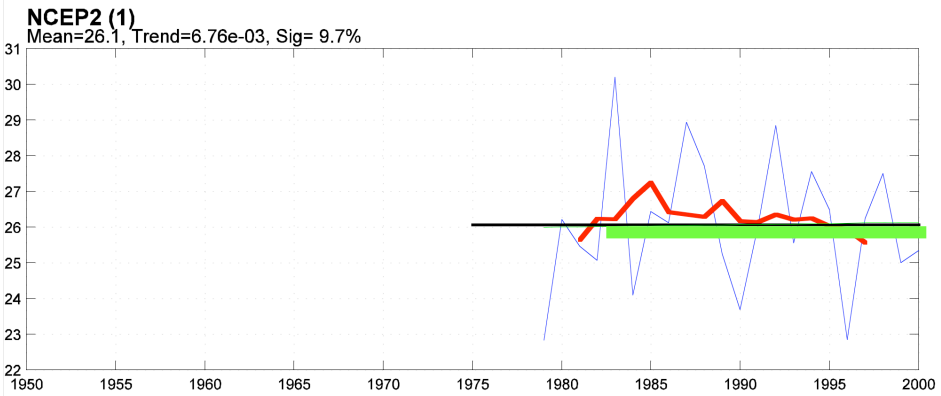
DJF Hadley cell index

(Mitas and Clement 2004)

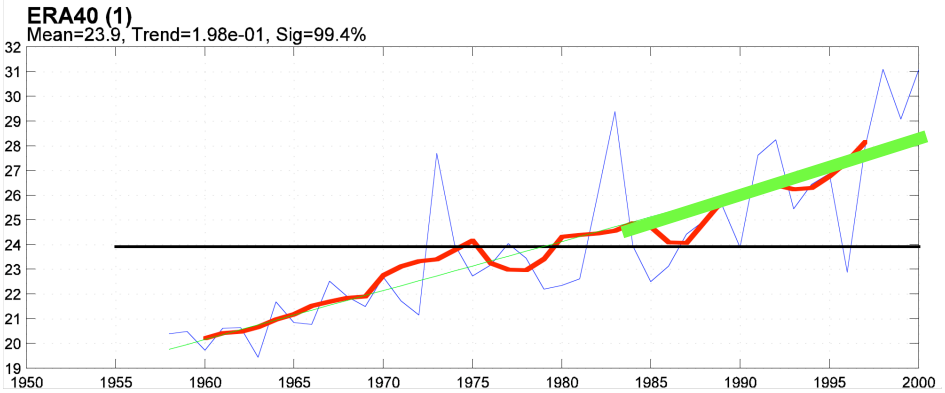
NCEP 1



NCEP 2



ERA40



JJA Hadley cell index

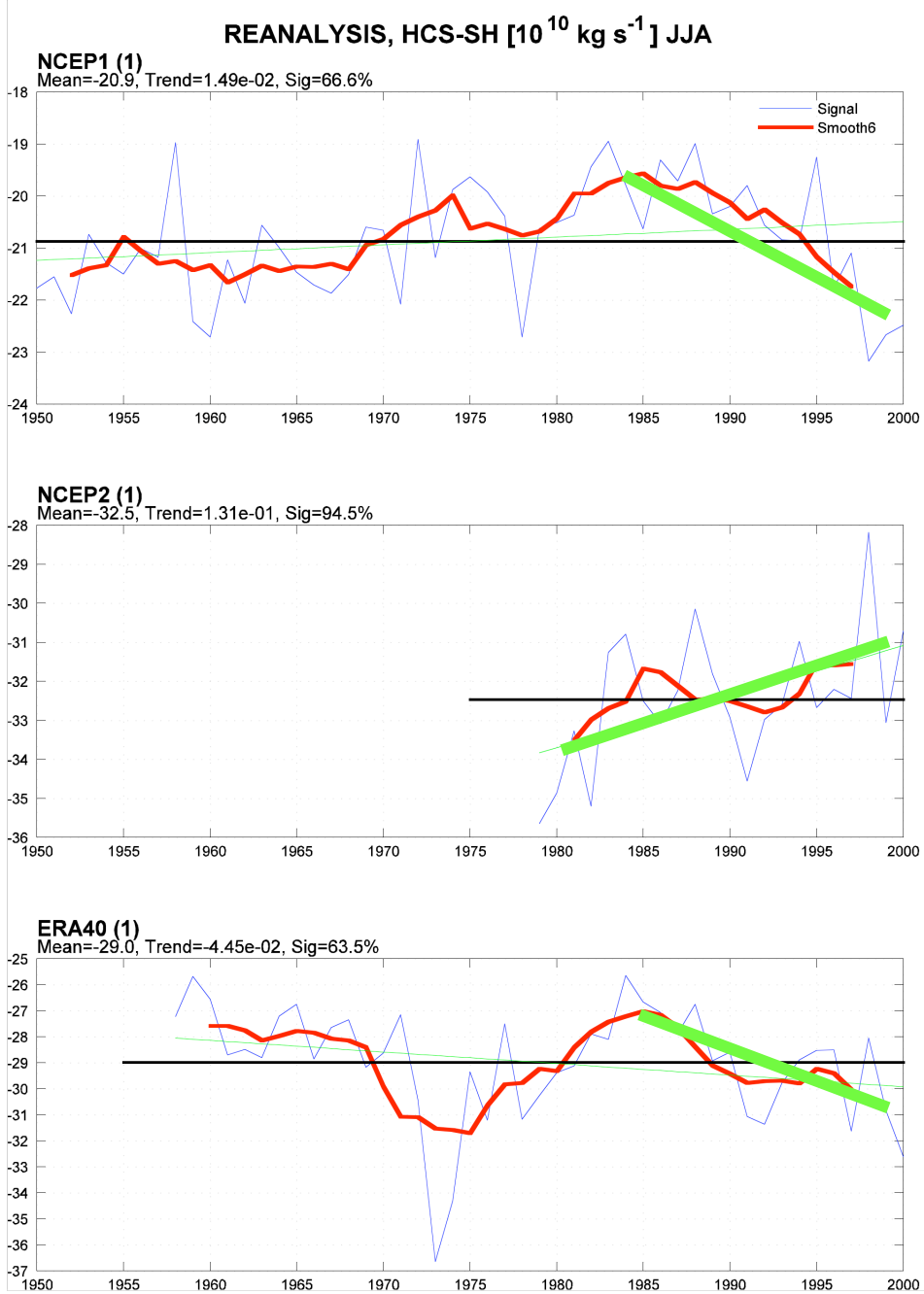
(Mitas and Clement 2004)

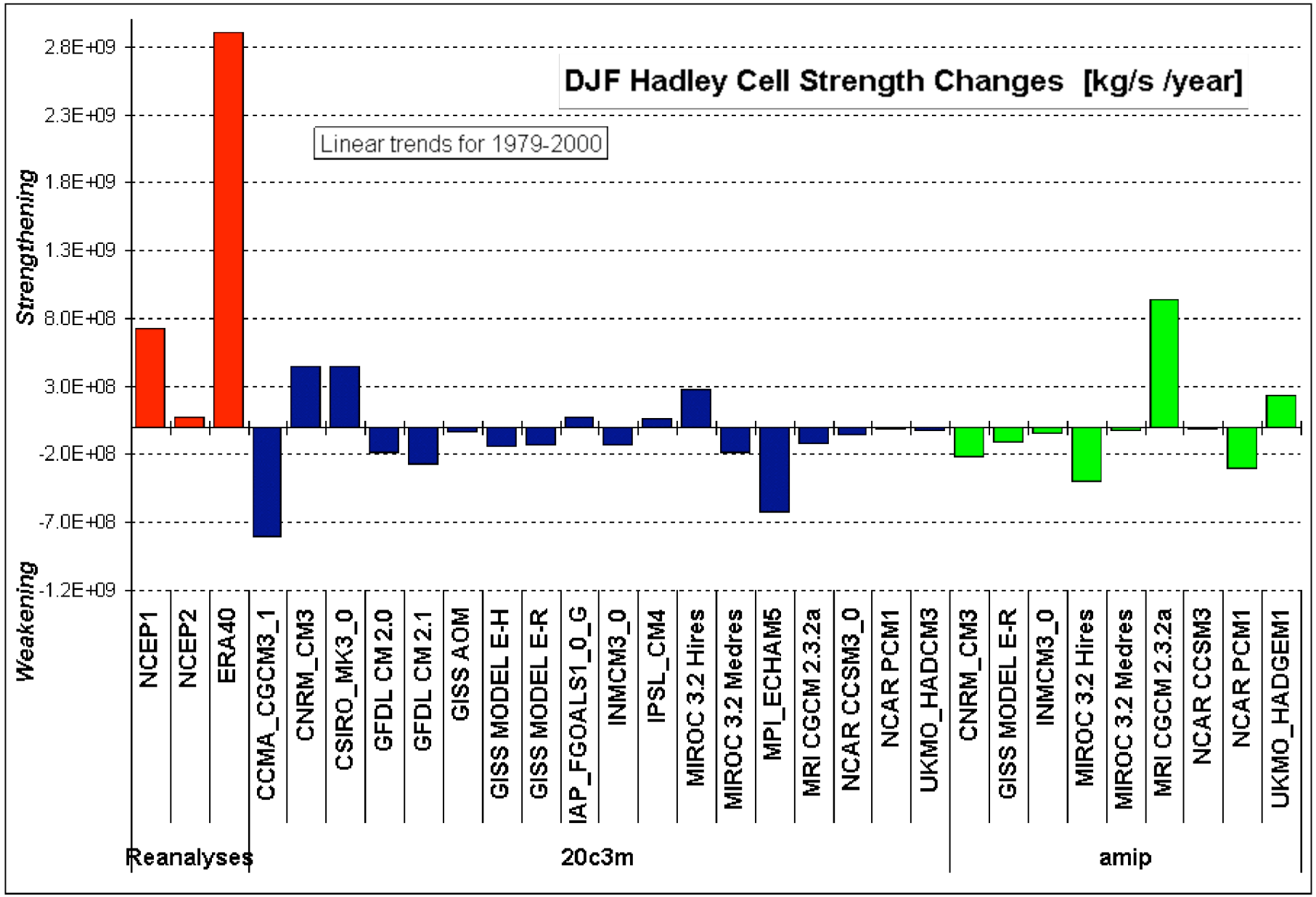
NCEP 1

Strengthening

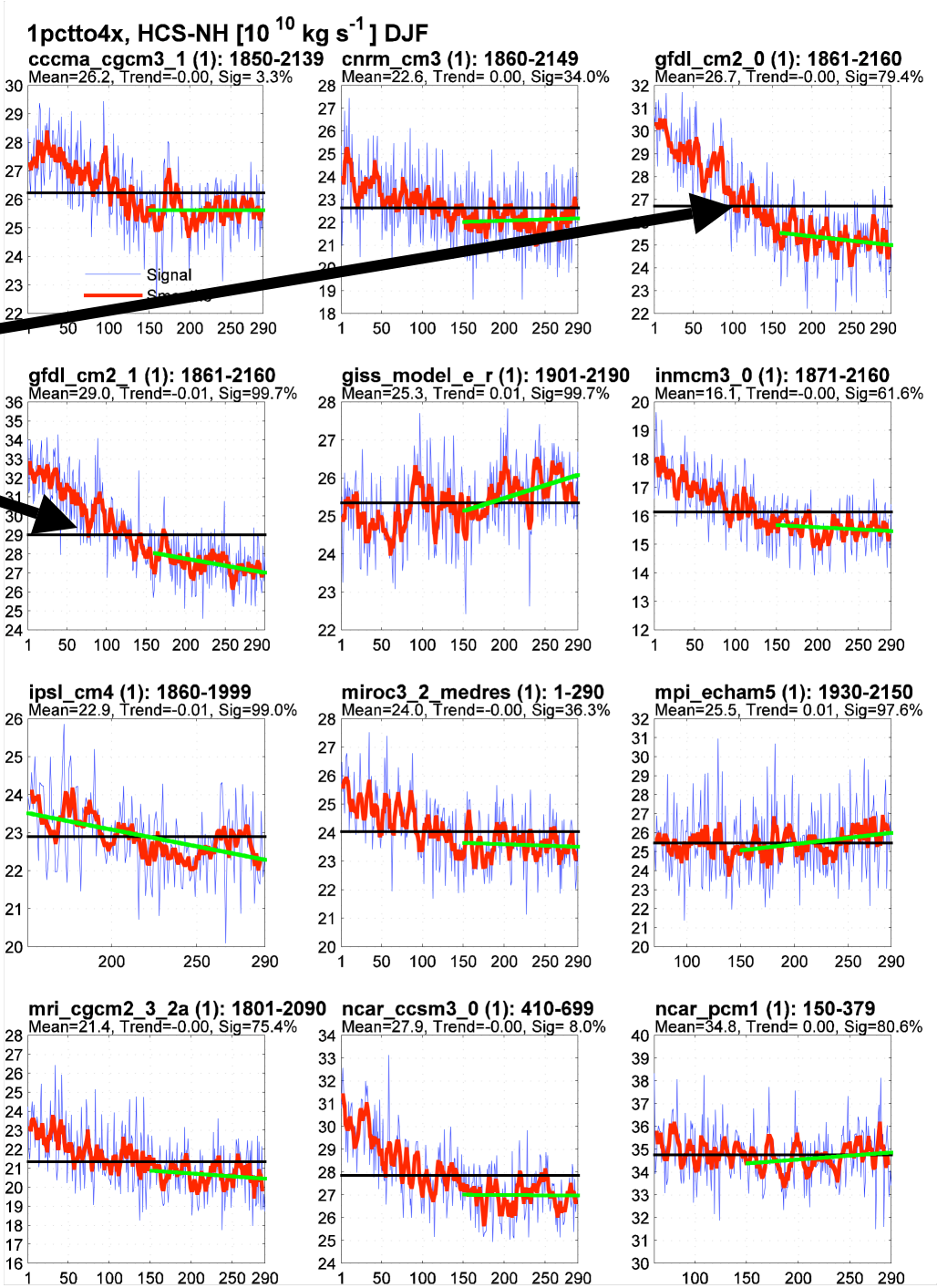
NCEP 2

ERA40




DJF Hadley Cell Strength Changes [kg/s /year]
Linear trends for 1979-2000
Strengthening
Weakening
2.8E+09
2.3E+09
1.8E+09
1.3E+09
8.0E+08
3.0E+08
-2.0E+08
-7.0E+08
-1.2E+09
NCEP1
NCEP2
ERA40
CCMA_CGCM3_1
CNRM_CM3
CSIRO_MK3_0
GFDL CM 2.0
GFDL CM 2.1
GISS AOM
GISS MODEL E-H
GISS MODEL E-R
IAP_FGOALS1_0_G
INMCM3_0
IPSL_CM4
MIROC 3.2 Hires
MIROC 3.2 Medres
MPI_ECHAM5
MRI CGCM 2.3.2a
NCAR CCSM3_0
NCAR PCM1
UKMO_HADCM3
CNRM_CM3
GISS MODEL E-R
INMCM3_0
MIROC 3.2 Hires
MIROC 3.2 Medres
MRI CGCM 2.3.2a
NCAR CCSM3
NCAR PCM1
UKMO_HADGEM1
Reanalyses
20c3m
amip

GFDL coupled model shows a ~15% reduction in Hadley cell strength



Why are the reanalyses different from the model simulations?

Approximate energy balance in the free troposphere:

$$Q = - \omega \, d\theta/dp$$

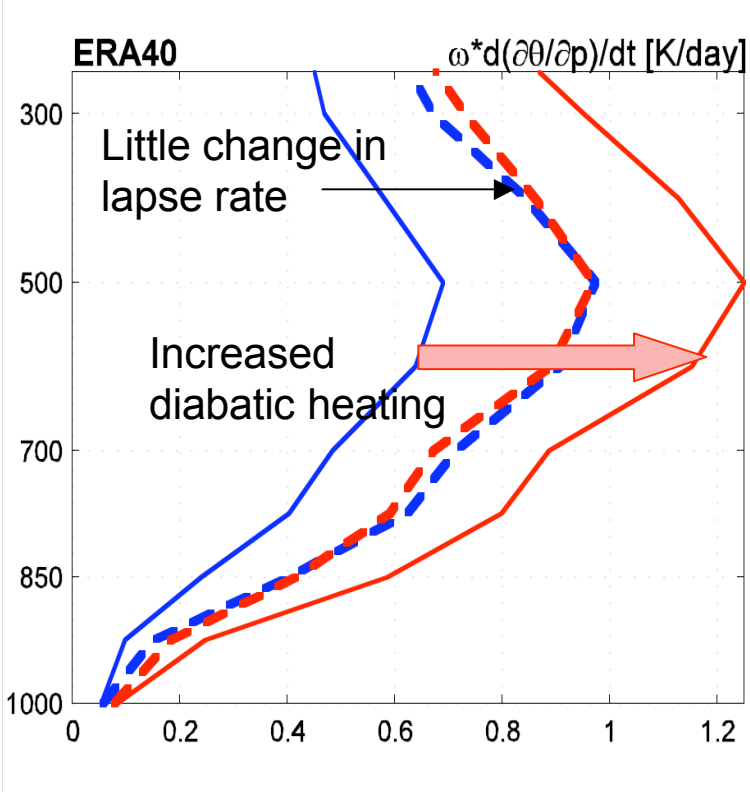
$$\Delta Q = - (\Delta\omega \, \overline{d\theta/dp} + \overline{\omega} \, \Delta d\theta/dp) + R$$

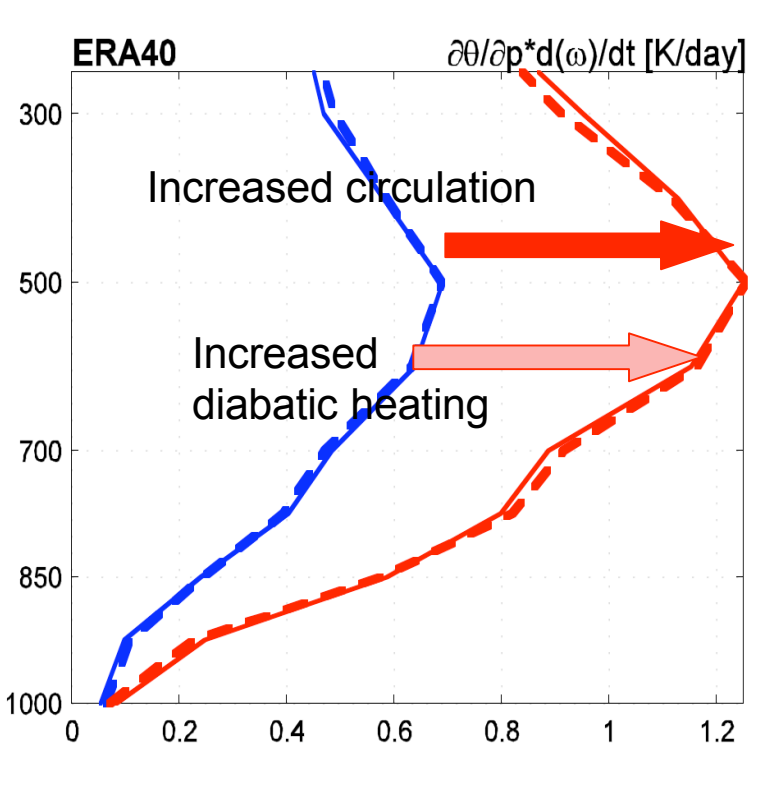
Heating

Stronger vertical motion

Larger lapse rate

ERA40: Change in the DJF Diabatic Heating (1950-2000)
Averaged over 0 – 15S

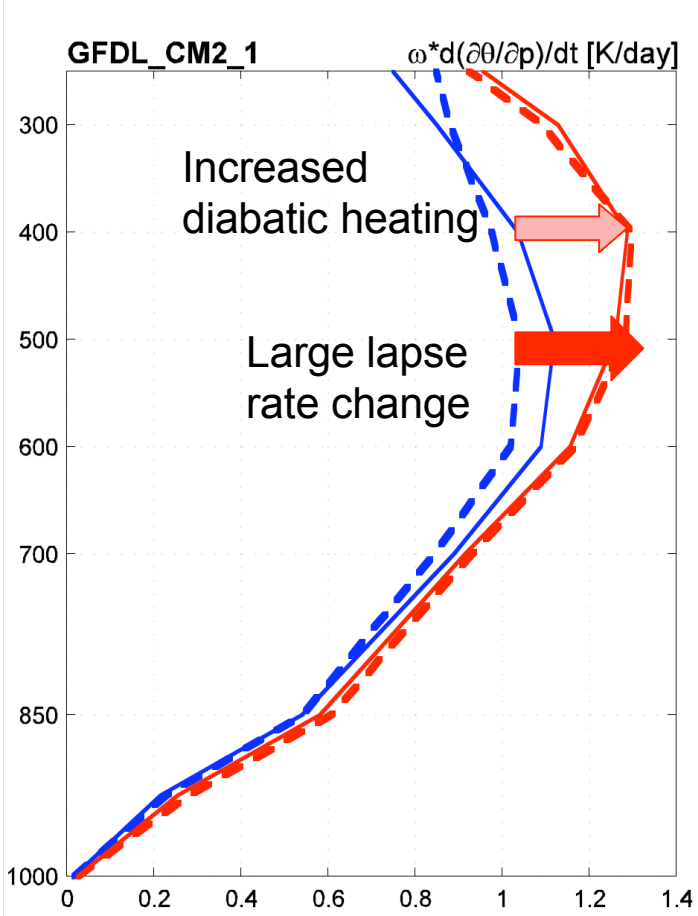


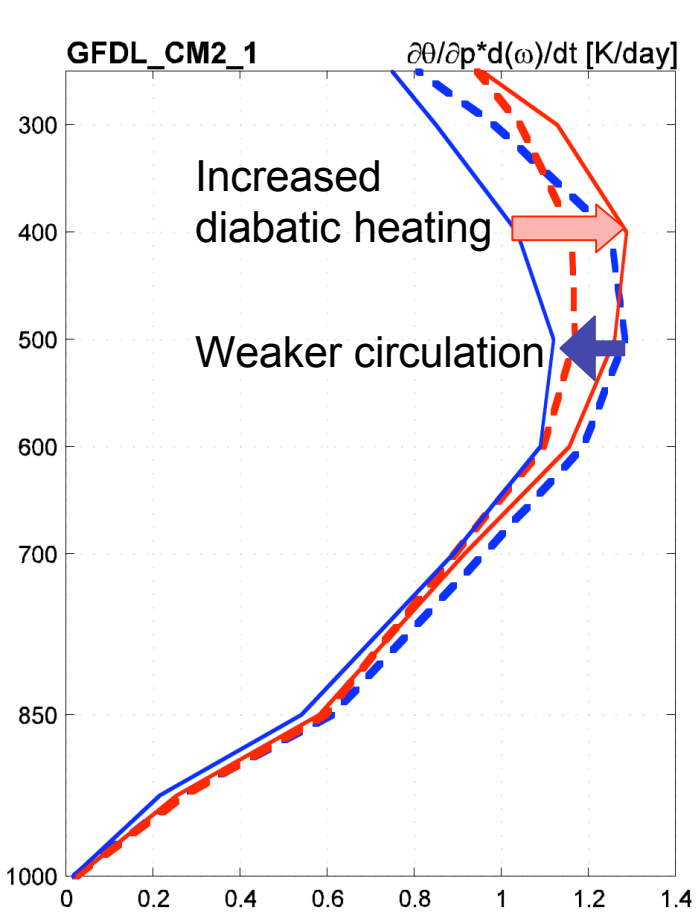


$\overline{\omega}\,\Delta\,d\theta/dp$

$\Delta\omega\;\overline{d\theta/dp}$

GFDL model: Change in the DJF Diabatic Heating (present to 4xCO2) averaged over 0 – 15S

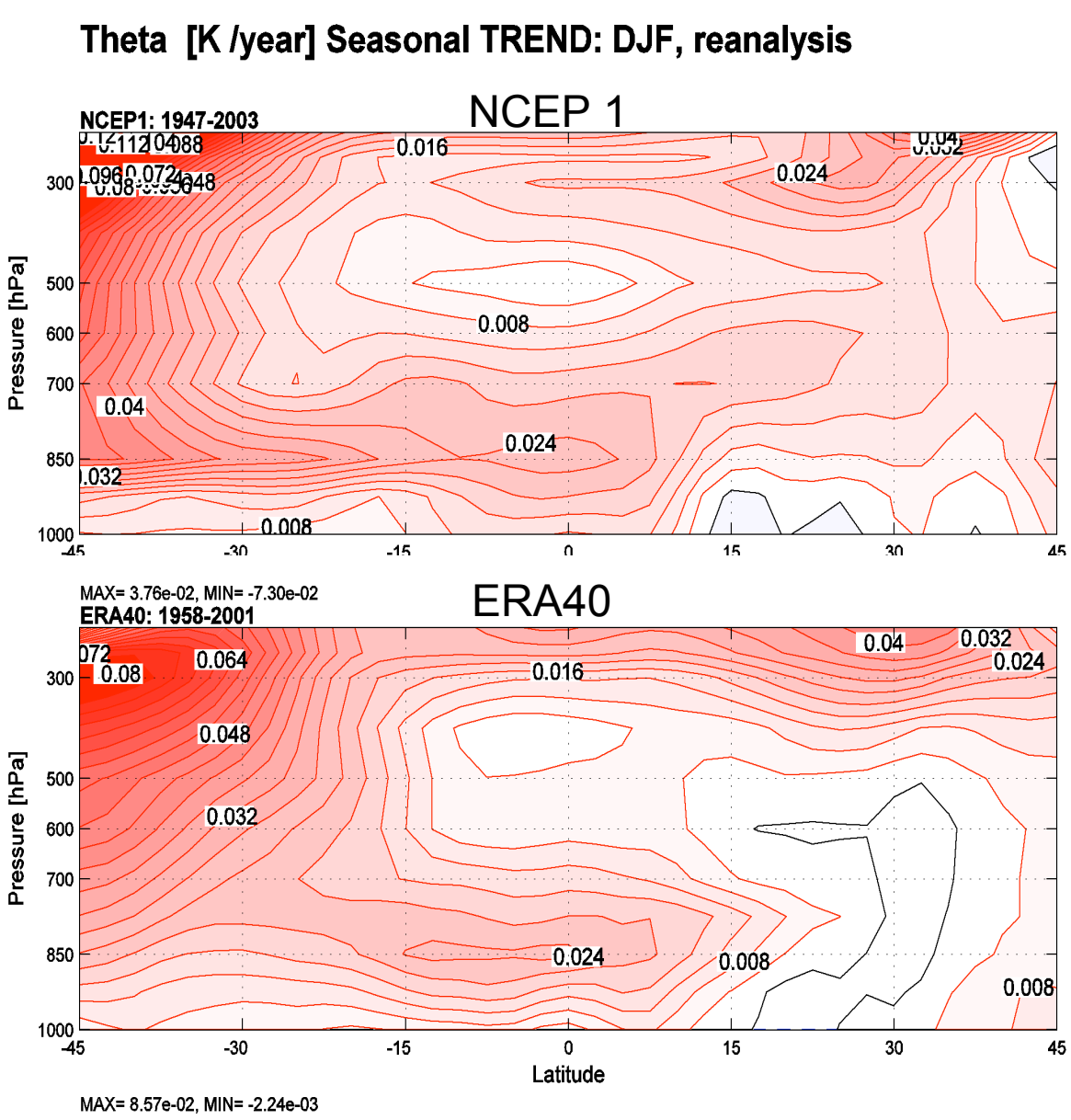




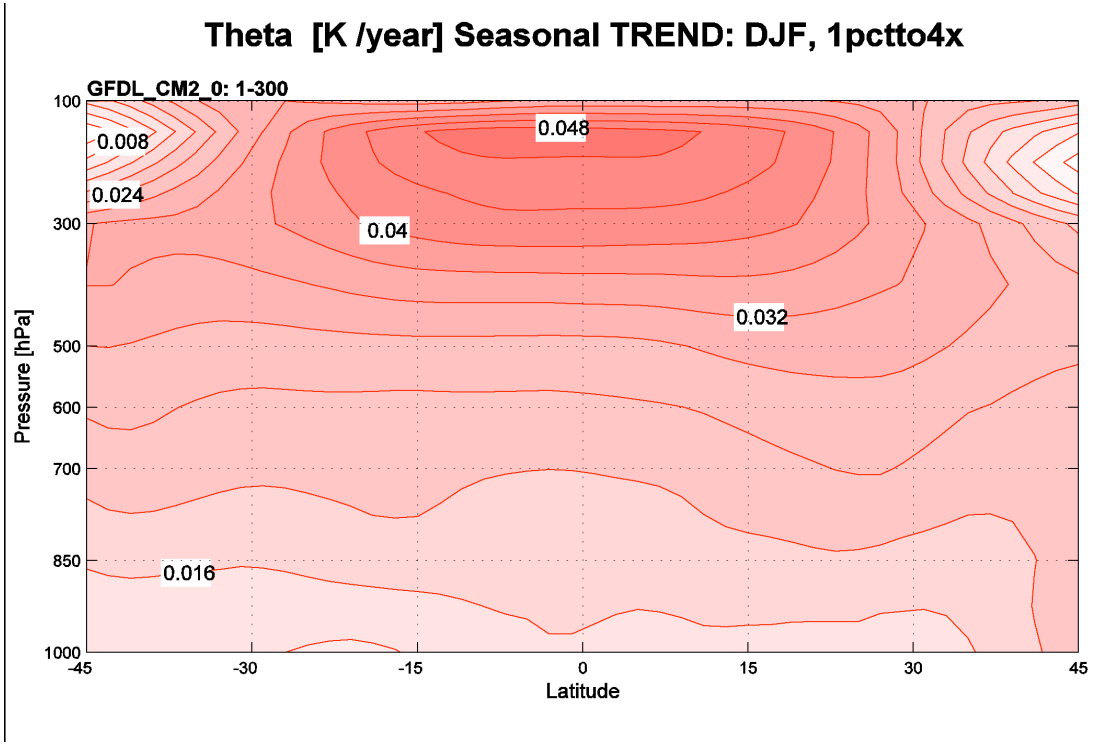
$\overline{\omega}\,\Delta\, d\theta/dp$

$\Delta\omega\ \overline{d\theta/dp}$

Reanalyses show minimum warming in the mid-troposphere (as in UAH satellite record and NOAA and UKMO radiosondes)



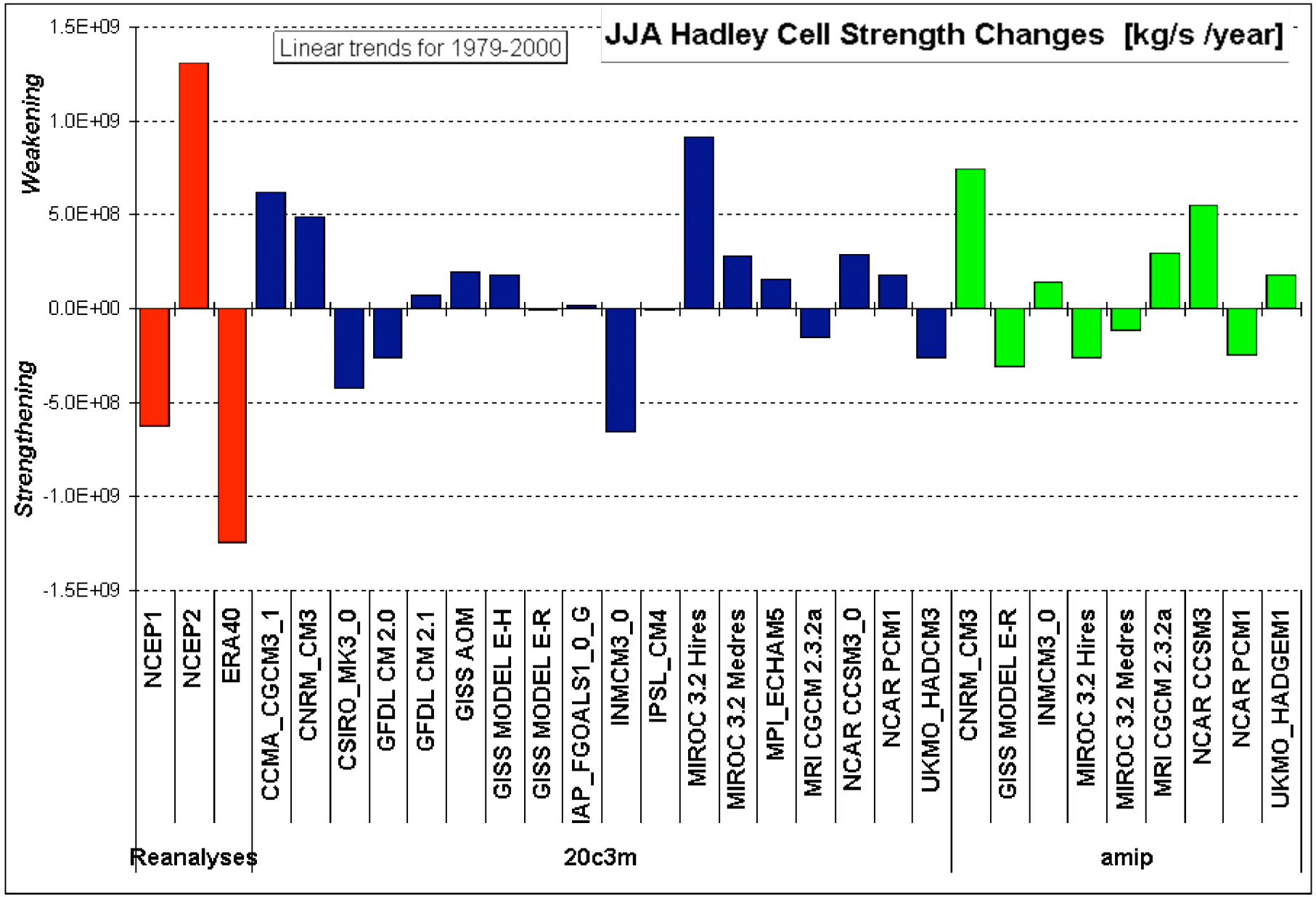
Models show amplification of warming aloft (as in RSS satellite record)

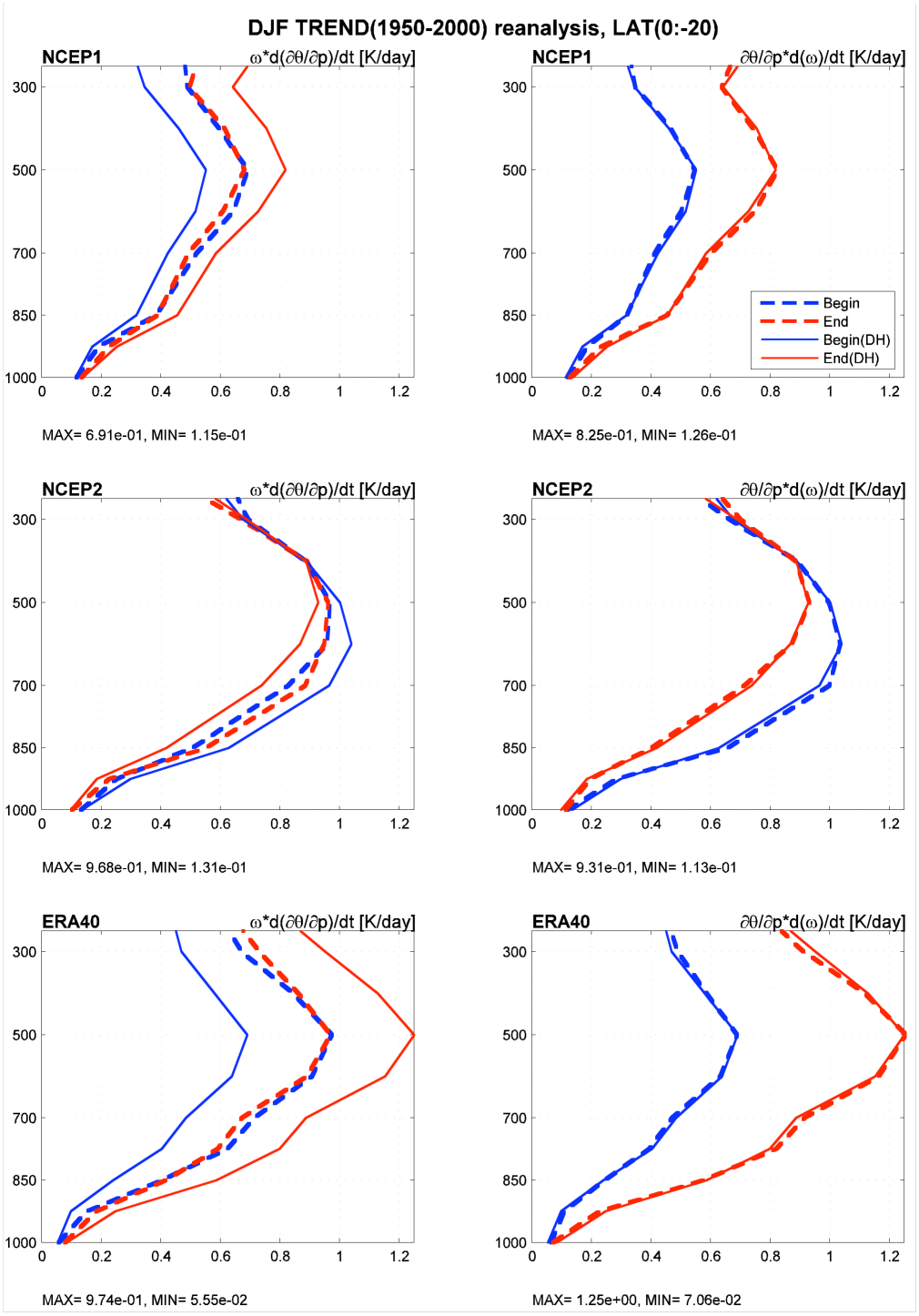


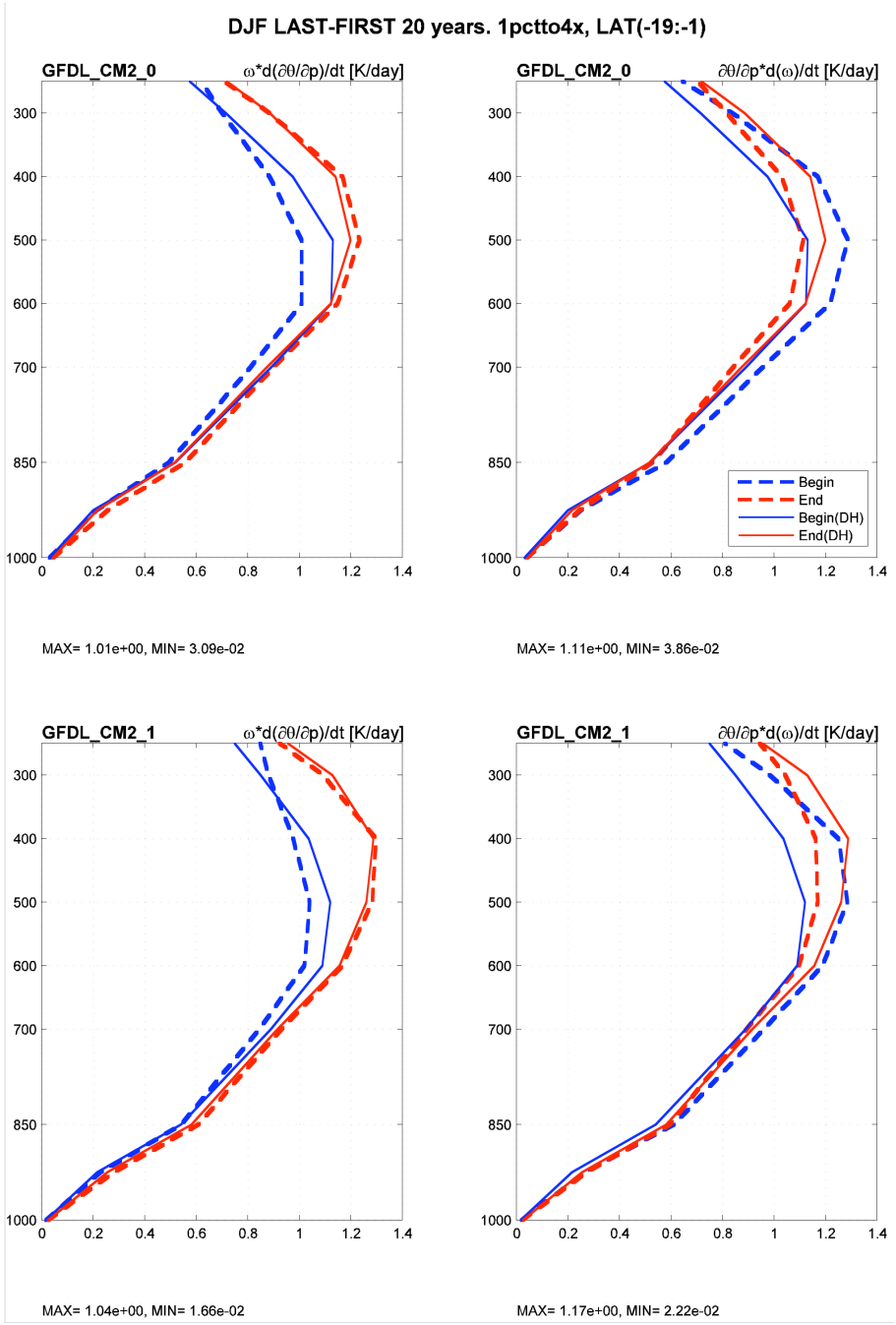
Which is right?

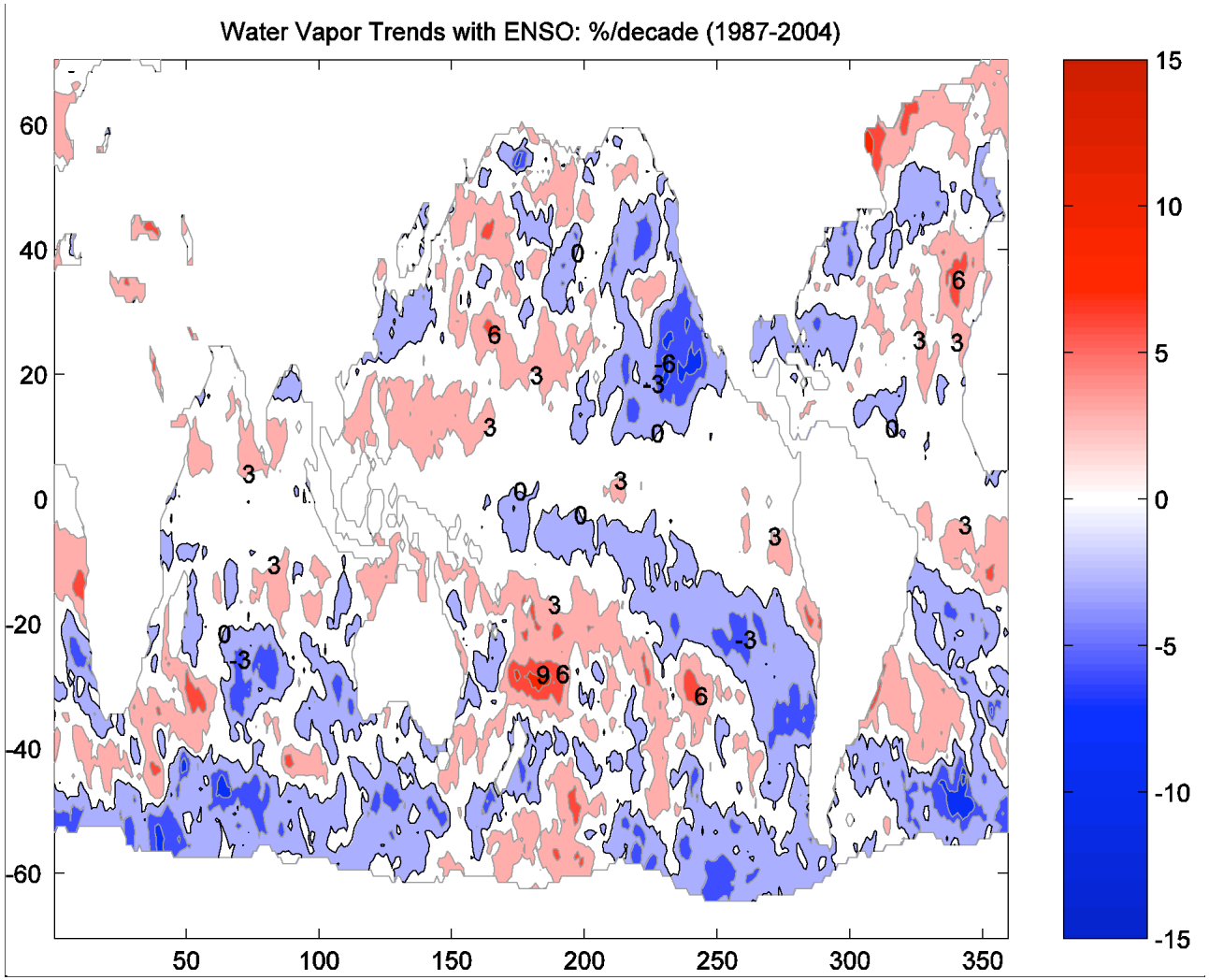
Conclusions

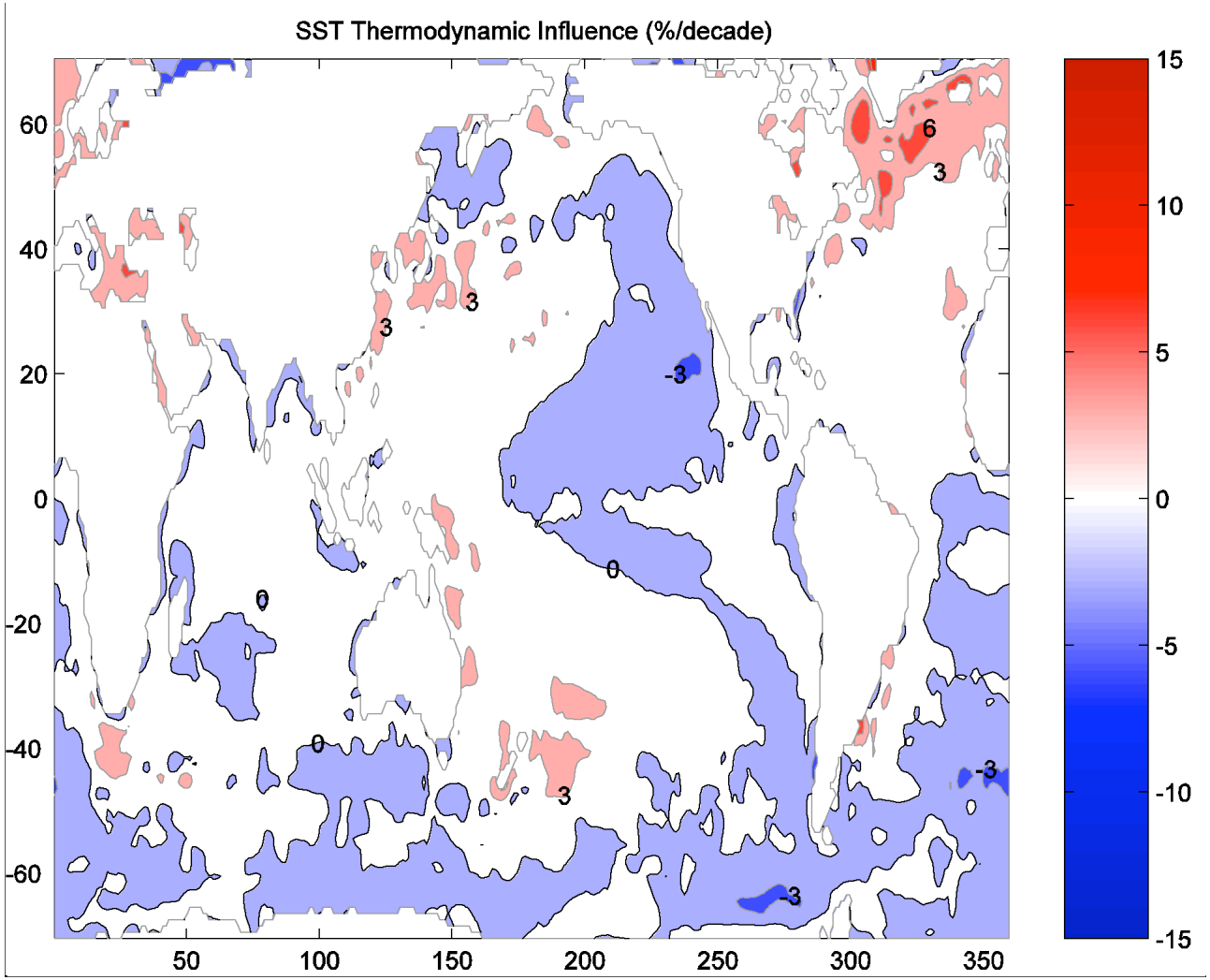
- NCEP1 and ERA40 show increasing strength of Hadley cell for DJF and JJA over the last 2 decades (NCEP2 does not)
- This is not consistent with IPCC 20th century runs or AMIP model runs
- Heat balance analysis suggests that the difference is related to difference in the vertical temperature structure response to climate change
- Which is consistent with CERES data? *(In AM2, increased absorbed SW (reduced low cloud cover) is consistent with a weaker circulation)*

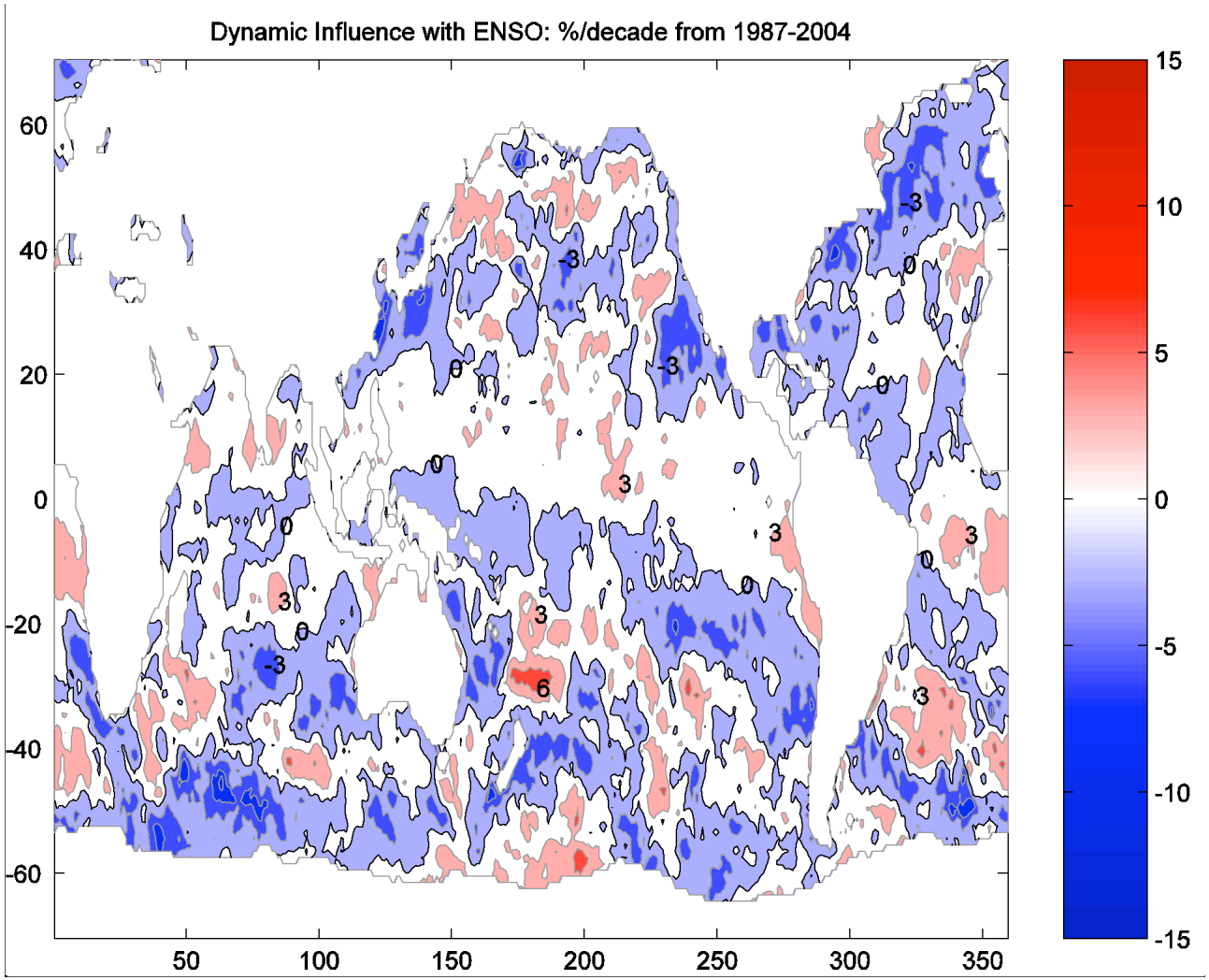

JJA Hadley Cell Strength Changes [kg/s /year]
Linear trends for 1979-2000
Weakening
Strengthening
1.5E+09
1.0E+09
5.0E+08
0.0E+00
-5.0E+08
-1.0E+09
-1.5E+09
NCEP1
NCEP2
ERA40
CCMA_CGCM3_1
CNRM_CM3
CSIRO_MK3_0
GFDL CM 2.0
GFDL CM 2.1
GISS AOM
GISS MODEL E-H
GISS MODEL E-R
IAP_FGOALS1_0_G
INMCM3_0
IPSL_CM4
MIROC 3.2 Hires
MIROC 3.2 Medres
MPI_ECHAM5
MRI CGCM 2.3.2a
NCAR CCSM3_0
NCAR PCM1
UKMO_HADCM3
CNRM_CM3
GISS MODEL E-R
INMCM3_0
MIROC 3.2 Hires
MIROC 3.2 Medres
MRI CGCM 2.3.2a
NCAR CCSM3
NCAR PCM1
UKMO_HADGEM1
Reanalyses
20c3m
amip


DJF TREND(1950-2000) reanalysis, LAT(0:-20)
NCEP1
ω*d(∂θ/∂p)/dt [K/day]
MAX= 6.91e-01, MIN= 1.15e-01
NCEP1
∂θ/∂p*d(ω)/dt [K/day]
MAX= 8.25e-01, MIN= 1.26e-01
Begin
End
Begin(DH)
End(DH)
NCEP2
ω*d(∂θ/∂p)/dt [K/day]
MAX= 9.68e-01, MIN= 1.31e-01
NCEP2
∂θ/∂p*d(ω)/dt [K/day]
MAX= 9.31e-01, MIN= 1.13e-01
ERA40
ω*d(∂θ/∂p)/dt [K/day]
MAX= 9.74e-01, MIN= 5.55e-02
ERA40
∂θ/∂p*d(ω)/dt [K/day]
MAX= 1.25e+00, MIN= 7.06e-02
300
500
700
850
1000
0
0.2
0.4
0.6
0.8
1
1.2


DJF LAST-FIRST 20 years. 1pctto4x, LAT(-19:-1)
GFDL_CM2_0
ω*d(∂θ/∂p)/dt [K/day]
GFDL_CM2_0
∂θ/∂p*d(ω)/dt [K/day]
Begin
End
Begin(DH)
End(DH)
MAX= 1.01e+00, MIN= 3.09e-02
MAX= 1.11e+00, MIN= 3.86e-02
GFDL_CM2_1
ω*d(∂θ/∂p)/dt [K/day]
GFDL_CM2_1
∂θ/∂p*d(ω)/dt [K/day]
MAX= 1.04e+00, MIN= 1.66e-02
MAX= 1.17e+00, MIN= 2.22e-02


Water Vapor Trends with ENSO: %/decade (1987-2004)
60
40
20
0
-20
-40
-60
50
100
150
200
250
300
350
15
10
5
0
-5
-10
-15


SST Thermodynamic Influence (%/decade)
60
40
20
0
-20
-40
-60
50
100
150
200
250
300
350
15
10
5
0
-5
-10
-15
6
3
3
3
-3
0
0
0
3
-3
-3


Dynamic Influence with ENSO: %/decade from 1987-2004
60
40
20
0
-20
-40
-60
50
100
150
200
250
300
350
15
10
5
0
-5
-10
-15

Tropical climate trends

Edition 2 data with altitude correction (courtesy of T. Wong)